STRATAFORM Plume Study: Analysis and Modeling

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LONG-TERM GOAL

My long-term goal is to understand the mechanics of river-plume transport of sediment and its influence on the trapping and dispersion of sediment on the continental shelf. This effort will also contribute to the development of predictive models of sediment dispersal and sedimentary strata formation.

OBJECTIVES

I am investigating the influence of river plumes on the delivery of sediment to continental margins, based on analysis of observations during floods of the Eel River in 1997 and 1998 and application of a three-dimensional numerical model. The objectives of this analysis and modeling study are 1) to quantify the delivery of sediment by the plume to different regions of the shelf under varying forcing conditions; 2) to investigate the influence of particle aggregation on the sediment transport; and 3) to use the numerical model to investigate the variability of flood deposition at event-scale, decadal, and longer timescales.

APPROACH

A major part of the effort in 1999 focussed on analysis of the moored and "rapid response" observations of the 1997 and 1998 flood events. The analysis included several issues, including the physical oceanographic regime of the Eel River shelf during floods, the sediment transport processes within and beneath the plume, the settling velocity of sediment within the plume, and the generation of fluid mud layers and hyperpycnal flows. Three manuscripts were submitted as a result of this analysis.

A 3-dimensional numerical model (the Princcton Ocean Model) was used to simulate the plume structure and to determine the influence of different forcing variables on the trajectory of suspended sediment. The initial phase of modeling uses an idealized domain, with a straight, uniform continental shelf that is similar in cross-section to the Eel shelf. These simulations are particularly useful for examining the basic physical mechanisms controlling the structure and variability of the plume and the sediment transport processes. The second phase of modeling includes a realistic domain, based on the actual bathymetry of the Eel shelf and with realistic forcing. Bottom boundary layer processes are being incorporated into the realistic model, including the important influence of surface gravity waves. These simulations allow us to compare the model runs to observations, thus to assess the accuracy with which the model represents the actual regime. The realistic simulations also provide a means of examining the processes in far greater detail than can be accomplished with data analysis, based on the assumption that the model is providing an accurate representation of the actual processes.

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A student named Dan McDonald is investigating the plume "lift-off" problem, the dynamics of the river plume as it first separates from the bottom. Because the mouth of the Eel is logistically infeasible for a shipboard study of plume lift-off, we have chosen a system of similar scale but more manageable sea conditions. McDonald has made measurements in the Fraser River, in British Columbia, during flood conditions in the summer of 1999, during which the flow was similar to the maximum flood conditions of the Eel in 1997.

WORK COMPLETED

The data analysis is essentially complete, except insofar as it relates to model development. Three manuscripts have been submitted that acknowledge the support of this project (Geyer et al., submitted; Traykovski et al., submitted, and Hill et al., submitted).

A large number of idealized runs of the numerical model have been implemented, and several realistic simulations have been performed. The bottom boundary layer formulation that includes internal gravity waves is under development, and preliminary results should be available by the Ocean Sciences meeting in 2000.

McDonald assembled an excellent data set of the plume lift-off in the Fraser River during the summer of 1999.

RESULTS

The most important result of the data analysis has been to quantify the sediment transport accomplished by the plume during a variety of forcing conditions. The plume regime is characterized by two very different states: a "fast" regime when the winds are from the south and the plume moves rapidly northward; and a "slow" regime when northerly winds arrest the motion of the plume and cause it to spread offshore (Geyer et al., submitted). During the fast regime, sediment is carried 50 km or more along the inner shelf before settling, whereas during the slow regime sediment settles out within 10 km of the mouth. In neither regime does the plume carry sediment seaward of the inner shelf. This surprising result indicates that bottom boundary layer processes must provide the cross-shelf transport between the inner shelf and the mid-shelf flood deposit.

The trapping of sediment by the plume on the inner shelf causes rapid accumulation of mud in water depths of 20–40 m. High wave energy in these shallow depths easily resuspends this sediment and keeps it mobile. Analysis of the 1998 timeseries data (Traykovski et al., submitted) indicates that a large wave event following a series of floods remobilized the recently deposited mud on the inner shelf, producing a dense suspension of fluid mud. There is evidence that this mud flowed down across the shelf as a hyperpycnal flow, at least as far as the 60 m isobath. This mechanism is the most likely explanation for the transport of sediment from the temporary deposits on the inner shelf to the mid-shelf deposits.

Detailed analysis of the variation of suspended sediment concentration within the plume indicates that there is not a strong variation in settling velocity with wind speed, contrary to the initial estimates. Most of the variability of settling is explained by the variation of plume speed, rather than by variations in settling velocity (Hill et al., submitted). Floculation is an important determinant of the sediment settling velocity, and it appears that roughly half the sediment settles as flocs within 10 km of the river mouth. However, the fraction of floculated sediment does not vary as much as expected with changes in forcing conditions. There do appear to be large differences in the floculation rate between the extreme flood conditions of 1997 and the more moderate floods of 1998.

The detailed examination of plume dynamics in the numerical model is revealing a complex cross-shelf circulation regime within and beneath the plume. The momentum of the plume is an important driving variable, as is Ekman transport and density-driven, cross-shelf motions. The analysis of idealized and realistic model simulations will provide significant new insights into the dynamics of river plumes as well as to better explain how the plume transports sediment.

McDonald has just gotten started with analysis of the plume lift-off problem. The data look great, and he should be able to come up with some valuable insights about the physical structure of the lift-off zone and its impact on mixing, sediment transport and particle aggregation in the plume.

IMPACT/APPLICATION

The results of the Rapid Response plume study have forced a major revision in the conceptual model of how flood deposits form on the Eel Shelf. The processes being observed here probably find broader relevance to river systems with narrow, mountainous drainage basins (as characteristic of most of the Pacific Rim). The trajectory of a river and its associated sediment cannot be ascertained by considering only the climatological conditions; instead, the conditions occurring during discharge event have to be considered in conjunction with the sediment discharge. The tight coupling of the modeling in this study with observations provides more detailed insights into the processes than could be obtained without the combination, and it provides the most effective path toward a predictive modeling capability for coastal environments.

TRANSITIONS

I am working closely with Harris and Signell at USGS to incorporate their boundary layer modeling technique into the 3-d model. Hill, Milligan and I have made major progress on determining the controls on settling velocity of the Eel River plume. I have provided Traykovski with Rapid Response CTD data and helped him in the development of a model for hyperpycnal transport in the bottom boundary layer. I have communicated the key observed features and dynamical processes of the plume to Morehead and Syvitski, which should help keep their plume modeling efforts on track. I am also working with Julie Pullen at Oregon State University with the implementation of a nested grid numerical model of the Eel shelf.

RELATED PROJECTS

I am involved with a study of plume dynamics as it relates to harmful algal blooms in the Gulf of Maine, in collaboration with Don Anderson (WHOI) with funding from NOAA and NSF as part of the ECOHAB project. I am working on studies of sediment and contaminant transport in the Hudson River estuary with funding by the ONR Harbor Processes Program and the Hudson River Foundation. There are similarities in the characteristics of sediment trapping and transport processes in the two systems. Similar modeling techniques are being used in the Hudson estuary projects as in the STRATAFORM study.

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